The cooperative Internet of Things enabled Smart Grid

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***Abstract*—The strong coupling of Information and Communication (ICT) technologies – especially via the usage of networked embedded devices – with the energy domain, is leading to a sophisticated dynamic ecosystem referred to as the Internet of Energy. In the last mile of the Smart Grid i.e. the future smart home, heterogeneous devices will be able to measure and share their energy consumption, and actively participate in house-wide or building wide energy management systems. The emerging Smart Grid will heavily depend on cooperation that will emerge at various layers (horizontally and vertically), and on the interaction with networked embedded systems that will be realizing its sensing and actuation functionality. We focus here on the enabling aspects of cooperation between the real world such as the Internet of Things and its interactions in the smart house and Smart Grid era.**

I. Introduction

In existing electricity infrastructure we are witnessing a typical centralized approach where few powerful central stations broadcast energy to the different consumers. However in order to tackle the ever rising need for energy and comply with social and economic demands of our times, we move towards increasing the usage of alternative energy resources which are smaller and decentralized. This leads to a very dynamic future energy network, where electricity will be produced in a distributed way, where customers will be not only consumers but also producers (hence they are called prosumers), and where bidirectional interaction between producers, consumers and other entities will be possible.

The emerging Internet of Energy [8], [1], and more specifically its core entity i.e. the Smart Grid, is a highly dynamic complex ecosystem of energy production and consumption parties that heavily uses Information and Communication Technologies (ICT) in order to be more efficient compared to its current traditional operation. Additionally the Smart Grid enables the creation of new innovative services based on bidirectional interaction of its stakeholders.

In order to realize the promise of Smart Grid, a key element would be to have timely monitoring and control. The functionality offered by the the networked embedded devices that would realise the monitoring and control part is crucial for the success of the Smart Grid. For instance smart meters is are the key for monitoring energy consumption. However in parallel the bidirectional interaction is pursued i.e. that there is an adaptation on the behavior of the prosumer device based on the information that it receives e.g. electricity price. Due to developments in the embedded systems, the energy consuming/producing devices will be no more considered as black-boxes but will also get interconnected, which will provide fine-grained info e.g. energy optimization per device. It is also expected that they will provide their functionality as a service and be able to consume on-line services (Internet of Services). As such they will be able to collaborate with other entities e.g. the PowerMatcher [9] and achieve common goals such as energy efficiency.

The bidirectional information exchange will put the basis for cooperation among the different entities, as they will be able to access and correlate information that up to now either was only available in a limited fashion (and thus unusable in large scale) or extremely costly to integrate. The Internet of Things however, bears the hope that networked embedded devices will not only be connected but will be able to exchange info over the Internet in an open way. Today we already have several examples of tiny devices depicting their basic functionality (e.g. status reporting, control functions etc) in a service oriented way (e.g. via web services, REST etc), which brings us one step closer to realize the vision of the Internet of Energy.

An example that depicts that the Smart Grid will be a collaborative service ecosystem is the following. A prediction for sunny and windy weather, will probably mean that more energy will be produced by "green" generators. This info can also flow into energy production plans of power plans that can now reduce their production. In parallel factories can plan to schedule energy hungry tasks during that time as electricity will be available from local generators (e.g. photovoltaic panels), and electric cars can fully charge benefiting from low electricity prices. What we will witness is that information will flow into a system of systems like the Smart Grid, it will be evaluated locally and affect its operation multiply. Due to the dynamic distributed nature of Smart Grid, as well as its large scale, optimizations will result at local level, and negotiations and cooperation among all entities will eventually lead to energy efficiency.

II. Cooperating Objects

The rapid advances in computational and communication part in embedded systems, is paving the way towards highly sophisticated networked devices that will be able to carry out a variety of tasks not in a standalone mode as usually done today, but taking into full account dynamic and context specific information. These "objects" will be able to cooperate, share information, act as part of communities and generally be active elements of a more complex system. The close interaction of the business and real world will be achieved by auxiliary services provided in a timely fashion from networked embedded devices. These will be able to collaborate not only among them but also with on-line services, that will enhance their own functionality.

These Cooperating Objects [10] may hold the key towards Smart Grid's full potential. The domain of Cooperating Objects is a cross-section between (networked) embedded systems, ubiquitous computing and (wireless) sensor networks. An initial definition of coming from the European Commission co-funded project CONET (www.cooperating-objects.eu) states: Cooperating Objects consist of embedded computing devices equipped with communication as well as sensing or actuation capabilities that are able to cooperate and organize themselves autonomously into networks to achieve a common task. The vision of Cooperating Objects is to tackle the emerging complexity by cooperation and modularity. Towards this vision, the ability to communicate and interact with other objects and/or the environment is a major prerequisite. While in many cases cooperation is application specific, cooperation among heterogeneous devices can be supported by shared abstractions.

Generally Cooperating Objects possess the ability and possibly the willingness to work or act together, however their cooperation can be intentional or unintentional. Intentional cooperation can be forced (rare) or voluntary (the usual case). In a system view, Cooperating Objects have goals and work together because of one or more common (even partially common) goals or means to achieve the end-goals. Single Cooperating Objects are parts of teams; as such cooperative behavior may be shown at higher level e.g. group level, and not be clearly identifiable at object level.

There are several flavors of Cooperating Objects: Advanced Cooperating Objects can process the context of cooperation intentionally, act on it and intentionally extend it, change it or stop it. As such they may possess logic to understand semantics and build complex behaviors. This eventually means that they can be part of dynamic complex ecosystems. Of course a cooperating object is governed by its internal rules and constrained by its resources, however its behavior is the result of a negotiation and potential benefit yield with respect to the external collaboration.

In the context of Smart Grid, several entities can fall within the context drawn by Cooperating Objects. Typical examples are advanced smart meters, smart white label appliances, electric cars, various prosumer/consumption/production devices, alternative energy resources, etc. In typical cooperating object demonstrators, all of these are capable of providing their functionality (e.g. energy consumption, status, management etc) as a service that can be utilized to achieve better energy management in standalone mode or as part of more complex system.

III. Smart Houses in the Smart Grid

The smart house of the future will be able to collaborate with numerous external entities, let it be alternative energy resources, marketplaces, enterprises, energy providers etc. The *de facto* standard for high-level communication today is via (web) services, which allows for flexible functionality integration without revealing details for the implementation. Therefore the heterogeneity is hidden, while a common service-based interaction (Figure 1) is empowering the creation of sophisticated applications. As such the smart house will be part of a complex system of systems.

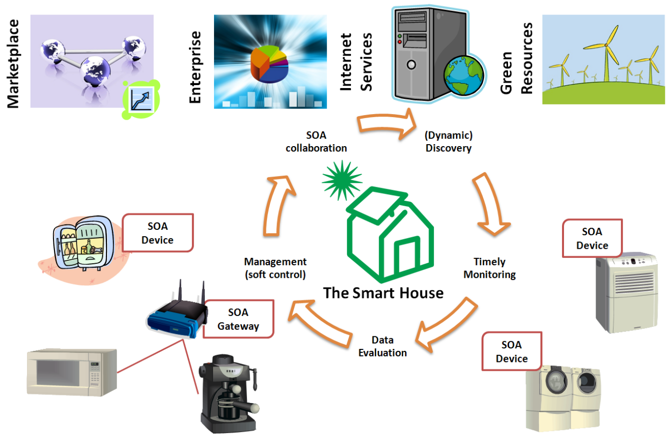

Fig. 1. Collaboration within the smart house and with external entities

Apart from the out-of-smart house interactions, the collaboration will be also visible within the house itself. We already have numerous protocols and even different technologies at hardware and communication layer, which inevitably will increase in the future. It is however a common belief that all of this heterogeneity will be hidden behind gateways and (service) mediators, which will eventually allow the device to tap into an IP-based infrastructure, using therefore Internet standards. Already today the IP protocol is developed further to run in tiny and resource constrained devices (6lowpan [12]), while with the IPv6 (and 6lowpan) any device will have its own IP address and therefore be directly addressable (and possibly uniquely identifiable).

Due to IP penetration down to discrete device level, it is expected that devices will not only provide their information for monitoring to controlling entities, but will be able to dynamically discover nearby devices and collaborate with them (as depicted in Figure 1). As such P2P interactions will emerge, which can be exploited by locally running applications that execute monitoring or controlling tasks. It is expected that each appliance manufacturer will make optimizations so that his device operates e.g. as efficient as possible. However it is beyond of current capabilities to see how this device will function collectively in an environment composed of other devices, as this environment is not standard and can not be known a priori. Here the collaboration concepts come in play, and the end-user (or another third party service provider) can create ad-hoc highly customizable applications that take into consideration the local context (e.g. of the specific house) and organize house-wide, building wide or even neighborhood wide optimizations.

Devices on the smart house are and will remain highly heterogeneous both in hardware and software. As such we need to find a way that this heterogeneity is abstracted and still communication among them (and collaboration) can be achieved. The development of middleware approaches that act as "glue" for device to business connectivity (and later also for device to device connectivity) is a viable approach. However it is more efficient if the heterogeneity is tackled at device level and only a limited part is delegated at the middleware. As such it is preferred that the devices offer standardized interfaces e.g. complying to ZigBee profiles and then limited connectors at the middleware side (for classes of devices and not specific to manufacturer or device) can directly enable their connectivity to on-line services and enterprise systems.

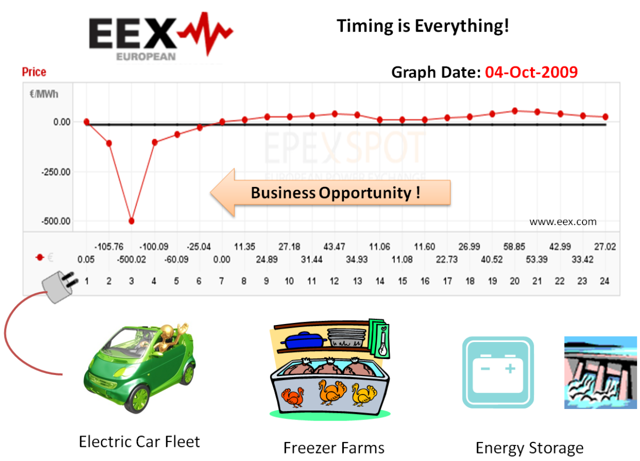

Fig. 2. Business opportunities on timely reaction to market events

In parallel to local collaboration, devices with advanced capabilities will be able to interact with network-based services hosted in enterprise systems, or simply somewhere on the Internet [5]. These devices will be able to enhance their own functionality in a dynamic way by invoking services that were not thought of at the time of device design. Price signals are often brought up as a key functionality that would affect the device behavior; for instance a device would get a price signal e.g. from the energy provider (or by monitoring or collaborating with an on-line service) and adapt its functionality.

In Figure 2 we can see the electricity price in the European Energy Exchange (EEX - www.eex.com). During the night of the 4^{th} of October 2009, this price dropped significantly due to overwhelming energy production from alternative energy resources (e.g. due to strong wind blowing over north-west of Germany) but without any consumers due to the late night. The negative price implies that electricity consumption would be money-rewarded (in order to guarantee grid stability). This is a business opportunity that could be exploited if cooperation (based on timely monitoring and control) was in place. In the Smart Grid era, this price drop would be immediately noticed by devices who would collaborate with on-line price monitoring services and would lead to kickstarting facilities that would consume or store energy such as electric car fleet companies, freezer farms, dams etc. For the businesses that can react efficiently this is a win-win situation as they can monetarily benefit from the negative price and also charge the customers; similarly for the grid, stability is guaranteed.

IV. Dynamic Energy Product Labels

The Dynamic Energy Product Labeling is another example that shows how innovation can be achieved by Cooperating Objects in the context energy efficiency in the future Internet of Energy. Typical energy labels today provide static information about the energy consumed by the device only when it is operational. This is very limiting, as not other energy related activities are not considered, e.g. the energy consumed to produce the specific product, the energy consumed during transportation etc, but even the static info provided about the operational status may not hold true after some months of operation. In the era of Smart Grids and Cooperating Objects this can be differently tackled, i.e. more accurately and holistically.

If energy can be measured at fine grained level, e.g. during the discrete productions steps, during any logistic operations, during transportation etc, new dynamic energy-related information can be made available. Firstly, as we know exactly how much energy was consumed for a specific product in different parts of its lifecycle, can certify that for a specific product. Therefore customers get a fair view of the energy impact it had already as well as a good indicator about the future behavior of the device.

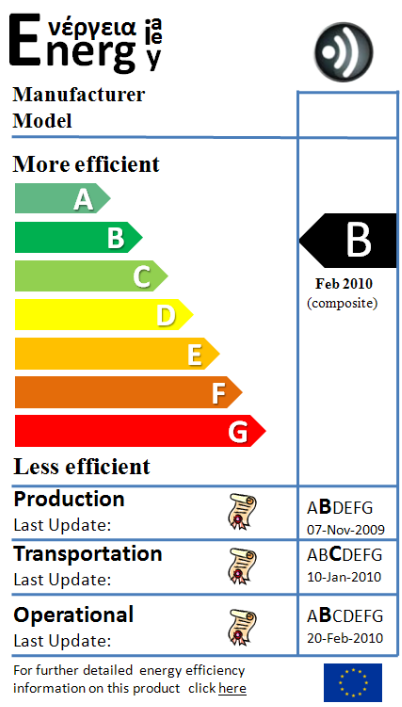

Fig. 3. Dynamic energy labels updated by Cooperating Objects

All energy related info can be monitored, offered to cooperating entities for their evaluation, and also captured in the energy labeling of a product such as the one depicted in Figure 3, where the exact amount of energy spent to produce it is named as well as the one consumed for the transportation of it etc. This will empower the consumer to select the product based on its carbon footprint or continuous energy consumption. Furthermore any significant deviation from the operational energy consumption may imply a malfunctioning device. In that case e-maintenance services in cooperation with the device could lead to an on-demand maintenance and limited downtime [3].

Although energy calculation is partially done today e.g. footwear and shoe companies, this is only based on estimations, is static, does not include logistics energy spent and stops when the product leaves the factory. However once the product leaves the manufacturer site, more energy is spent until it reaches its point of sale. Dynamic labeling that can be updated by authorized parties can help maintaining an accurate and real view on the total amount of energy consumed for the specific product. As such, the selection of products and tools will not be done merely based on their quality and productivity, but also their energy efficiency. We expect that in the short-term ISO standards for assessing energy efficiency will be available for more industry-wide transparency.

V. SOA-Ready devices: enabling cooperation

Interoperability is the capability of a product or system to interact and function with other products or systems, without any access or implementation restrictions. As such we can see that efficiently tackling the interoperability challenge is a mandatory aspect if any cooperation is to take place among devices.

A common practice especially in the enterprise world, it to hide heterogeneity behind service oriented architectures implemented by web services. Similarly the same idea has been proposed for devices; i.e. hide their heterogeneity via an abstract and common way to access their functionality, without focusing on the specific implementation at device level. The new OASIS WS-DD Specifications are an example of how this can be done for resource constrained devices. Based on Devices Profile for Web Services 1.1, SOAP-over-UDP 1.1, and Web Services Dynamic Discovery (WS-Discovery) 1.1, one can dynamically discover and communicate in an event based way with resource constrained devices.

Device Profiles for Web Services (DPWS) is a subset of Web service standards (such as WSDL and SOAP) that allows minimal interaction with Web services running on embedded devices. DPWS is the successor of Universal Plug and Play (UPnP) as in essence it specifies a protocol for seamless interaction with the services offered by different embedded devices. However DPWS is fully aligned with Web Services technologies. The various specifications DPWS include support for (secure) messaging, service discovery and description, and eventing for resource-constrained devices. Since an earlier version of DPWS specifications has been around for a while (since 2005), current versions of Windows VISTA, Windows 7 and Windows Embedded CE already ship with the capability to discover such SOA-ready devices in the network. Open source implementations of the DPWS specifications such as the DPWS4j toolkit (www.soa4d.org) and WS4D (www.ws4d.org) exist.

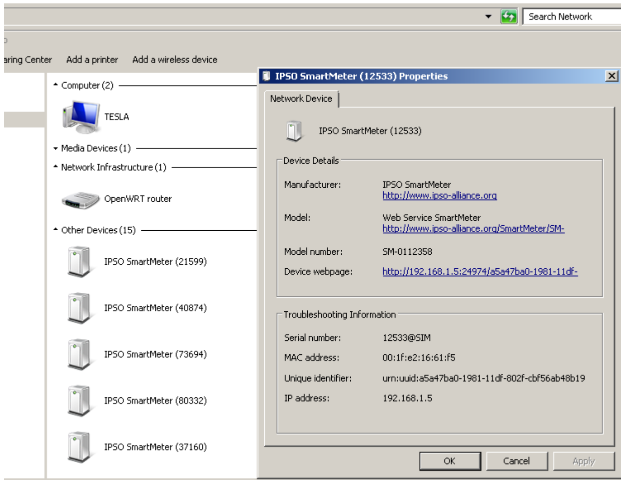

Fig. 4. A SOA-Ready smart meter: metering functionality offered via event-based web services

As a proof of concept we have wrapped conventional meters with web services and used a Windows 7 machine to dynamically discover them and acquire their metadata, as depicted in Figure 4. Each SOA-ready device provides an interface to external entities that can manage it, or it can even call itself external sources of information e.g. via a web service acquire the electricity price, and then adjust its behavior accordingly. This is a possible way that would enable the implementation of the case depicted in Figure 2. Initial evaluations show that implementing web services on devices might be an effective way to tackle the interoperability requirement [11], [7], and also for the Smart Grid domain the approach looks promising [6].

VI. Market Estimation for Cooperating Objects

The domain of Cooperating Objects is still at its dawn; however its impact is estimated to be so broad and significant that could drastically change the future application and services. Numerous market analyses seem to point out towards this direction also. It is important to understand that Cooperating Objects is a huge domain with applications in spawning several fields, and therefore it is very difficult to set the limits and estimate its total value.

The main focus of Cooperating Objects is in coupling the physical and virtual worlds; they do this via monitoring and control activities. The overall market where Cooperating Object technologies are contributing is expected to grow significantly until 2020 (as depicted in Figure 5). Software and services will have a higher growth than the average total market mainly due to the high growth of Communication and networking, Simulation and modeling, Decision support and ERP, Integration [4].

As it can be seen in Figure 5, the investments in the powergrid, buildings and household appliances will be more than doubled in the next years, which will lead to the widespread existence of networked embedded systems, upon which sophisticated cooperative approaches can be build. The world monitoring and control market is expected to grow from € 188

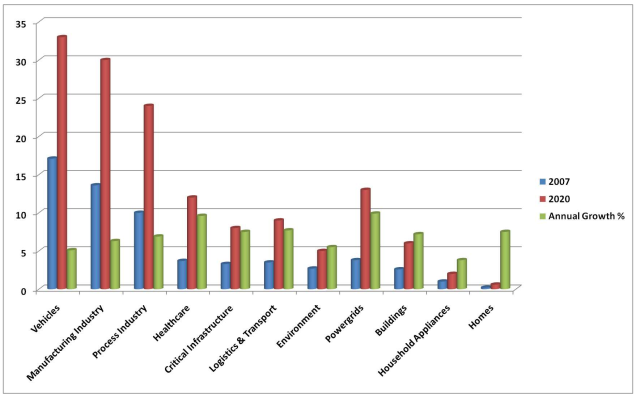

Fig. 5. Monitoring and control market 2007 – 2020 [4]

Bn in 2007, by €300 Bn, reaching approx. €500 Bn in 2020. The monitoring and control European market follows the same trends as the world one in terms of product repartition and also market product evolution. The European monitoring and control market will be reaching €143 Bn in 2020. Especially the next generation of services is expected to strengthen the trend towards mash-up of information from heterogeneous sources and realization of new innovative functionality based on cooperation.

VII. Research directions

The Cooperating Objects is an emerging domain, which may have a significant impact on the Smart Grid. However, we are still at the dawn of the era, and significant research will need to be invested especially on the interaction among the different entities of the Smart Grid under the prism of cooperation.

We need to invest on an event based infrastructure. With thousand of objects capable-of and willing-to cooperate, it will be impossible to stick to the traditional *pull* approaches, especially considering the side-effects such as the unnecessary network utilization. Therefore investment should be done on towards a publish/subscribe model, where the necessary entities can subscribe and get only the interesting for them events.

Timely monitoring and control support should also be available. Providing information exactly when it is needed, will be of key importance for business decisions. Therefore it has to be guaranteed that fine grained monitoring can be done and that the quality of monitoring services can be achieved. Once this is achieved, and high precision data can be evaluated either locally, on the network or on business systems, the need for control and more specifically management of the device at enterprise level will be needed in order to close the loop. Basic monitoring and control capabilities exist today, but need to move out of the vendor-locked implementations and participate in collaborations with other objects.

Discovery of real-world services [5], preferably in a dynamic way, by humans, enterprise systems and other Cooperating Objects is of critical importance, as it forms a requirement for cooperation flourish. In a world of autonomous and mobile Cooperating Objects, applications will be modeled with focus on functionality that will be dynamically discovered and exploited from the environment. As such semantic support might also be needed to ease the tasks of integrating the discovered capabilities into the actions of the Cooperating Objects.

Openness and interoperability among the various highly heterogeneous Cooperating Objects will need to be tackled, something that will be quite challenging in the Smart Grid domain [2]. Again semantics might help, however auxiliary services that would ease cooperation should also be offered by the infrastructure. Several groups work already at various layers e.g. communication, information exchange (e.g. OASIS Energy Interoperation TC) etc to empower the Smart Grid. Using service based interactions, which are common to the business world, also on the Internet of Things, might provide the necessary glue for easy integration.

Finally, it is clear that the future Smart Grid will be highly dynamic and complex. Emulators/simulators that will allow us to experiment with this dynamic system would be of great use. Today we only have specific simulators for very limited issues, however none that can actually tackle in a holistic way the envisioned Smart Grid infrastructure – not to speak about the complex interactions among its entities. A testbed for research to evaluate the effects of various algorithms, as well as autonomic management approaches might prove extremely useful.

VIII. Conclusions

A revolution in energy domain is underway, namely the Smart Grid. Its basic building blocks are the existing efforts of the Internet of Things and Internet of Services, that come together with cooperation as the key goal. In Smart Grids networked embedded devices are making the electricity grid itself, the homes, the factories etc. smarter, enabling and increasing the collaboration among them. In the Smart Grid era, it is expected that all devices will offer their functionalities as services that other entities can (dynamically) discover and use. In such highly distributed heterogeneous infrastructures it is clear that the challenges tackled by the Internet of Things can have a real impact, empower the Smart Grid and greatly affect the domain and its future value added services.

The introduction of widespread collaboration at all layers of the Smart Grid will signal also a paradigm change, which will reshape various business domain including the Energy one. As IT technologies empower traditional processes and enable sophisticated cooperative services to emerge, many challenges such as security, trust, and privacy will gain importance, but also opportunities will arise. Once these are adequately tackled, it is expected that a new breed of innovative services and business application that we can not anticipate today, will be possible.

IX. Acknowledgments

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